

CONTROL APPARATUS OF VARIABLE VALVE TIMING MECHANISM AND METHOD THEREOF

Field of the Invention

The present invention relates to a control apparatus and a control method of a variable valve timing mechanism that varies valve timing of engine valves by changing a rotation phase of a camshaft relative to a crankshaft.

Related Art of the Invention

Heretofore, there has been known a control apparatus of a variable valve timing mechanism as disclosed in Japanese Unexamined Patent Publication No. 2000-297686.

Such a conventional control apparatus comprises a cam sensor outputting a signal at a reference rotation position of a camshaft, and a crank angle sensor outputting a signal at a reference rotation position of a crankshaft.

In such a control apparatus, an angle of from the reference rotation position of the crankshaft to the reference rotation position of the camshaft is detected based on signals from the cam sensor and the crank angle sensor.

Then, an actuator of the variable valve timing mechanism is feedback controlled so that the above angle (rotation phase) reaches a desired value.

According to the above constitution, the rotation phase is detected at each fixed crank angle.

However, a feedback control of actuator is typically executed at each fixed period of time (for example, 10ms).

Therefore, at a low rotation time of engine, a detection period of rotation phase becomes longer than a period of feedback control.

At this time, the feedback control is executed based on the rotation phase which differs from an actual rotation phase, during a detection value of the rotation phase is updated. As a result, there occurs the overshooting of rotation phase.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to enable to prevent the overshooting of rotation phase when a detection period of rotation phase becomes longer than a period of feedback control.

In order to accomplish the above-mentioned object, the present invention is constituted so that a rotation phase is detected based on a signal synchronized with the rotation of a crankshaft and a signal synchronized with the rotation of a camshaft, and also controlled variable of an actuator of a variable valve timing mechanism is detected, to convert the controlled variable into the rotation phase with a transfer function representing the variable valve timing mechanism.

Then, an estimation value of the rotation phase is calculated based on the rotation phase detected based on the rotation synchronized signals and the rotation phase obtained by converting the controlled variable, and an operation signal is output to the actuator based on the estimation value and a desired value.

The other objects and features of the invention will become understood from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of a system structure of an internal combustion engine in an embodiment.

Fig. 2 is a cross section view showing a variable valve timing mechanism in the embodiment.

Fig. 3 is an exploded perspective view of the variable valve timing mechanism.

Fig. 4 is a cross section view along A-A in Fig. 2.

Fig. 5 is a cross section view along A-A in Fig. 2.

Fig. 6 is a flowchart showing a resetting process of a counter CPOS in the embodiment.

Fig. 7 is a flowchart showing a counting up process of the counter CPOS in the embodiment.

Fig. 8 is a flowchart showing a calculation process of a detection value θ_{det} for each cam signal CAM in the embodiment.

Fig. 9 is a flowchart showing a feedback control of rotation phase in the embodiment.

Fig. 10 is a block diagram showing a setting process of an actual angle θ_{now} in the embodiment.

Fig. 11 is a time chart showing a correlation among the detection value θ_{det} , a conversion value θ_{pr} and the actual angle θ_{now} .

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 is a structural diagram of an internal combustion engine for vehicle in an embodiment.

In Fig. 1, in an intake pipe 102 of an engine 101, an electronically controlled throttle 104 is disposed, and air is sucked into a combustion chamber 106 via electronically controlled throttle 104 and an intake valve 105.

In electronically controlled throttle valve 104, a throttle valve 103b is driven to open/close by a throttle motor 103a.

A combusted exhaust gas is discharged from combustion chamber 106 via an exhaust valve 107, and is purified by a front catalyst 108 and a rear catalyst 109, and then emitted into the atmosphere.

Intake valve 105 and exhaust valve 107 are driven to open/close by cams disposed to an intake side camshaft 134 and to an exhaust side camshaft 111, respectively.

Intake side camshaft 134 is disposed with a variable valve timing mechanism 113.

Variable valve timing mechanism 113 changes a rotation phase of intake side camshaft 134 relative to a crankshaft 120, to vary valve timing of intake valve 105.

Further, an electromagnetic type fuel injection valve 131 is disposed on an intake port 130 for each cylinder.

Fuel injection valve 131 injects fuel adjusted at a predetermined pressure toward intake valve 105, when driven to open by an injection pulse signal from an engine control unit (ECU) 114.

ECU 114 incorporating therein a microcomputer receives detection signals from various sensors.

Engine control unit 114 controls electronically controlled throttle 104, variable

valve timing mechanism 113 and fuel injection valve 131 by calculation process based on the detection signals.

There are provided, as the various sensors, an accelerator opening sensor APS 116 detecting an accelerator opening, an air flow meter 115 detecting an intake air amount Q of engine 101, a throttle sensor 118 detecting an opening TVO of throttle valve 103b, and a water temperature sensor 119 detecting a cooling water temperature of engine 101.

Further, there is provided a crank angle sensor 117 outputting a reference crank angle signal REF at each 180° rotation of crankshaft 120 and also outputting a position signal POS at each unit angle (1° to 10°) rotation of crankshaft.

Furthermore, there is provided a cam sensor 132 outputting a cam angle signal CAM at each 90° rotation of intake side camshaft 134.

Note, since intake side camshaft 134 is rotated twice during crankshaft 120 is rotated once, 90° of intake side camshaft 134 corresponds to 180° of crankshaft 120.

ECU 114 calculates an engine rotation speed Ne based on a period of reference crank angle signal REF or the number of position signals POS generated per predetermined time of period.

Next, a constitution of variable valve timing mechanism 113 will be described based on Figs. 2 to 5.

Variable valve timing mechanism 113 comprises camshaft 134, a drive plate 2, an assembling angle adjusting mechanism 4, an operating apparatus 15 and a cover 6.

Drive plate 2 is transmitted with the rotation of engine 101 (crankshaft 120) to be rotated.

Assembling angle adjusting mechanism 4 is the one that changes an assembling angle between camshaft 134 and drive plate 2, and is operated by operating apparatus 15.

Cover 6 is mounted across a cylinder head (not shown in the figures) and a front end of a rocker cover, to cover front surfaces of drive plate 2 and assembling angle adjusting mechanism 4.

A spacer 8 is fitted with a front end (left side in Fig. 2) of camshaft 134.

The rotation of spacer 8 is restricted with a pin 80 that is inserted through a flange portion 134f of camshaft 134.

Camshaft 134 is formed with a plurality of oil galleries in radial.

Spacer 8 is formed with a flange 8a, a cylinder portion 8b extending axially from a front end surface of flange 8a, and a shaft supporting portion 8d formed on an outside of cylinder portion 8b, that is, the front end surface of flange 8a.

Shaft supporting portion 8d is disposed at three locations at even intervals on the outside of cylinder portion 8b, and is formed with a hole 8c parallel with an axial direction.

Further, spacer 8 is formed with a plurality of oil galleries 8r for supplying oil, in a radial direction.

Drive plate 2 is mounted to spacer 8 so as to be relatively rotated in a state where the axial displacement thereof is restricted by flange 8a.

A timing sprocket that is transmitted with the rotation of crankshaft 120 is formed on a rear outer periphery of drive plate 2, as shown in Fig. 3.

Further, on a front end surface of drive plate 2, three guide grooves 2g extending in radial are formed at each 120°.

Moreover, to an outer periphery portion of the front end surface of drive plate 2, a cover member 2c of annular shaped is fixed by welding or press fitting.

Above described assembling angle adjusting mechanism 4 is arranged on the front end portion side of camshaft 134 and drive plate 2, to change a relative assembling angle between camshaft 134 and drive plate 2.

Assembling angle adjusting mechanism 4 includes three link arms 14, as shown in Fig. 3.

Each link arm 14 is provided with, at a tip portion thereof, a cylinder portion 14a as a sliding portion, and is provided with an arm portion 14b extending from

cylinder portion 14a in an outer diameter direction.

A hole 14c is formed on cylinder portion 14a, while a hole 14d is formed on a base end portion of arm portion 14b.

Link arm 14 is mounted so as to be rotatable around a rotation pin 81, by inserting rotation pin 81 fitted into a hole 8c of spacer 8 through hole 14d.

On the other hand, cylinder portion 14a of link arm 14 is inserted into guide groove 2g of drive plate 2, to be mounted so as to be movable along guide groove 2g.

In the above constitution, when cylinder portion 14a receives an outer force to displace along guide groove 2g, rotation pin 81 transfers circumferentially by an angle according to a radial displacement amount of cylinder portion 14a.

Then, camshaft 134 is relatively rotated with respect to drive plate 2 due to the displacement of rotation pin 81.

Figs. 4 and 5 show an operation of assembling angle adjusting mechanism 4.

As shown in Fig. 4, when cylinder portion 14a is arranged on an outer periphery side of drive plate 2, rotation pin 81 on the base end portion is close to guide groove 2g, and this position is a most retarded position of valve timing.

On the other hand, as shown in Fig. 5, when cylinder portion 14a is arranged on an inner periphery side of drive plate 2, rotation pin 81 is pressed circumferentially to depart from guide groove 2g, and this position is a most advance position of valve timing.

The radial transfer of cylinder portion 14a in assembling angle adjusting mechanism 4 is performed by operating apparatus 15.

Operating apparatus 15 is provided with an operation conversion mechanism 40 and a speed increasing/reducing mechanism 41.

Operation conversion mechanism 40 is provided with a sphere 22 held in cylinder portion 14a of link arm 14, and a guide plate 24 coaxially formed so as to face the front face of drive plate 2.

Operation conversion mechanism 40 converts the rotation of guide plate 24

into the radial displacement of cylinder portion 14a of link arm 14.

Guide plate 24 is supported so as to be relatively rotatable with respect to an outer periphery of cylinder portion 8b of spacer 8 via a metal bush 23.

On a rear face of guide plate 24, a spiral guide groove 28 is formed, and on guide plate 24, an oil gallery 24r for supplying oil is formed.

Sphere 22 is fitted with spiral guide groove 28.

As shown in Figs. 2 and 3, a supporting panel 22a, a coil spring 22b, a retainer 22c and sphere 22 are inserted in this sequence into hole 14c disposed to cylinder portion 14a of link arm 14.

Retainer 22c is formed with a supporting portion 22d for supporting sphere 22 in a state where sphere 22 protrudes, and also formed, on an outer periphery thereof, with a flange 22f on which coil spring 22b is seated.

In an assembling condition as shown in Fig. 2, coil spring 22b is compressed, supporting panel 22a is pressed to the front face of drive plate 2, and sphere 22 is fitted with spiral guide groove 28.

Further, as shown in Figs. 4 and 5, spiral guide groove 28 is formed so as to gradually reduce a diameter thereof along a rotation direction R of drive plate 2.

Accordingly, if guide plate 24 is relatively rotated with respect to drive plate 2 in the rotation direction R, sphere 22 transfers to outside along spiral guide groove 28. Thus, cylinder portion 14a moves to outside as shown in Fig. 4, and rotation pin 81 connected with link arm 14 is dragged so as to become closer to guide groove 2g, so that camshaft 134 is relatively rotated in a retarded direction.

On the contrary, if guide plate 24 is relatively rotated with respect to drive plate 2 in an opposite direction to the rotation direction R from the above condition, sphere 22 transfers to inside along spiral guide groove 28. Thus, cylinder portion 14a transfers to inside as shown in Fig. 5, and rotation pin 81 connected with link arm 14 is pressed so as to depart from guide 2g, so that camshaft 134 is relatively rotated in an advance direction.

Speed increasing/reducing mechanism 41 will be described in detail.

Speed increasing/reducing mechanism 41 is for transferring (speed increasing) guide plate 24 with respect to drive plate 2 in the rotation direction R or for transferring (speed reducing) guide plate 24 with respect to drive plate 2 in the opposite direction to the rotation direction R.

Speed increasing/reducing mechanism 41 is provided with a planetary gear mechanism 25, a first electromagnetic brake 26 and a second electromagnetic brake 27.

Planetary gear mechanism 25 is provided with a sun gear 30, a ring gear 31, and a planetary gear 33 engaged with the both gears 30 and 31.

As shown in Figs. 2 and 3, sun gear 30 is formed integrally with an inner periphery on a front face side of guide plate 24.

Planetary gear 33 is rotatably supported by a carrier plate 32 fixed to the front end portion of spacer 8.

Ring gear 31 is formed on an inner periphery of an annular rotor 34 that is rotatably supported by an outer side of carrier plate 32.

Carrier plate 32 is fitted with the front end portion of spacer 8 and is fixed to camshaft 134 by a bolt 9 via a washer 37.

A braking plate 35 having a braking face 35b is fixed to a front end surface of rotor 34.

Further, a braking plate 36 having a braking face 36b is fixed to an outer periphery of guide plate 24 integrally formed with sun gear 30.

Accordingly, in planetary gear mechanism 25, if planetary gear 33 is not rotated but is revolved together with carrier plate 32, in a condition where first and second electromagnetic brakes 26 and 27 are not operated, sun gear 30 and ring gear 31 are rotated at the same speed.

If only first electromagnetic brake 26 is operated from the above condition, guide plate 24 is relatively rotated in a direction to be retarded with respect to carrier plate 32 (direction opposite to the R direction in Figs. 4 and 5).

On the other hand, if only second electromagnetic brake 27 is operated from

the above condition, a braking force is given to link gear 31 only, so that ring gear 31 is relatively rotated in a direction to be retarded with respect to carrier plate 32. Thus, planetary gear 33 is rotated, and the rotation of planetary gear 33 increases a speed of sun gear 30, so that guide plate 24 is relatively rotated to the rotation direction R side with respect to drive plate 2.

First and second electromagnetic brakes 26 and 27 are arranged so as to face braking faces 36b and 35b of braking plates 36 and 35, respectively.

Further, first and second electromagnetic brakes 26 and 27 include cylinder members 26r and 27r that are supported by pins 26p and 27p on a rear surface of cover 6, in floating states where only the rotation thereof are restricted by pins 26p and 27p.

These cylinder members 26r and 27r house therein coils 26c and 27c, respectively, and are also respectively mounted with friction members 26b and 27b that are pressed to braking faces 35b and 36b when power is supplied to each of coils 26c and 27c.

Cylinder members 26r and 27r, and braking plates 35 and 36 are formed of magnetic substance, such as iron, for generating a magnetic field when the power is supplied to each of coils 26c and 27c.

On the contrary, cover 6 is formed of non-magnetic substance, such as aluminum, for preventing leakage of magnetic flux at the time of power supply, and friction members 26b and 27b are formed of non-magnetic substance, such as aluminum, for preventing from being made to be permanent magnet, to be attached to braking plates 35 and 36 at the time of non-power supply.

The relative rotation of drive plate 2 and guide plate 24 is restricted by an assembling angle stopper 60 at the most retarded position and the most advance position.

Further, in planetary gear mechanism 25, a planetary gear stopper 90 is disposed between braking plate 35 formed integrally with ring gear 31, and carrier plate 32.

Operation conversion mechanism 40 described above is constituted such that a position of cylinder portion 14a of link arm 14 is maintained so that a relative assembling position between drive plate 2 and camshaft 134 does not fluctuate, in the

non-operating conditions of first and second electromagnetic brakes 26 and 27. Such a constitution will be described.

A driving torque is transmitted via link arm 14 and spacer 8 to camshaft 134 from drive plate 2. While, a fluctuating torque of camshaft 134 due to a reaction force from the engine valve is input from camshaft 134 to link arm 14, as a force F of a direction to connect pivoting points on both ends of link arm 14 from rotation pin 81.

Since cylinder portion 14a of link arm 14 is guided in radial along guide groove 2g, and also sphere 22 protruding forwards from cylinder portion 14a is fitted with spiral guide groove 28, the force F input via each link arm 14 is supported by the left and right walls of guide groove 2g and spiral guide groove 28 of guide plate 24.

Accordingly, the force F input to link arm 14 is divided into two components F_A and F_B orthogonal to each other, and these components F_A and F_B are received in directions orthogonal to a wall on the outer periphery of spiral guide groove 28 and orthogonal to one wall of guide groove 2g, respectively.

Therefore, cylinder portion 14a of link arm 14 is prevented from transferring along guide groove 2g. Thus, link arm 14 is prevented from being rotated.

Therefore, after guide plate 24 is rotated by the braking forces of respective electromagnetic brakes 26 and 27, and link arm 14 is rotated to a predetermined position, the position of link arm 14 is maintained and a rotation phase between drive plate 2 and camshaft 134 is held as it is, without the necessity of continuously providing braking force.

An operation of variable valve timing mechanism 113 will be described hereafter.

In the case where a rotation phase of camshaft 134 with respect to crankshaft is controlled to a retarded side, the power is supplied to second electromagnetic brake 27.

If the power is supplied to second electromagnetic brake 27, friction member 27b of second electromagnetic brake 27 contacts with brake plate 35, and a braking force is acted on ring gear 31 of planetary gear mechanism 25, so that sun gear 30 is increasingly rotated with the rotation of timing sprocket 3.

Guide plate 24 is rotated in the rotation direction R side with respect to drive

plate 2 by the increase rotation of sun gear 30, and as a result, camshaft 134 is displaced to the retarded side.

This displacement to the retarded side is restricted at the most retarded position shown in Fig. 4 by assembling angle stopper 60.

On the other hand, in the case where the assembling angle of camshaft 134 is displaced to the advance direction, the power is supplied to first electromagnetic brake 26.

Thereby, the braking force of first brake 26 acts on guide plate 24, and guide plate 24 is rotated in the direction opposite to the rotation direction R with respect to drive plate 2, so that camshaft 134 is displaced to the advance side.

This displacement to the advance side is restricted at the most advance position shown in Fig. 5 by assembling angle stopper 60.

ECU 114 sets a target advance value (target rotation phase) of camshaft 134 relative to crankshaft 120 based on engine operating conditions (load, rotation).

Further, ECU 114 measures a phase difference between the reference crank angle signal REF of crank angle sensor 117 and the cam angle signal CAM of cam sensor 132, to detect an advance value (rotation phase).

Then, ECU 114 feedback controls the power supply to first and second electromagnetic brakes 26 and 27, so that an actual advance value coincides with the target advance value.

Flowcharts in Fig. 6 to Fig. 8 show the process of detecting the advance value.

The routine shown in the flowchart of Fig. 6 is interruptedly executed at each time when the reference crank angle signal REF is output from crank angle sensor 117. In step S11, a counter CPOS counting up the number of generated position signals POS is reset to zero.

Further, the routine shown in the flowchart of Fig. 7 is interruptedly executed at each time when the position signal POS is output from crank angle sensor 117. In step S21, counter CPOS is counted up to 1.

Accordingly, counter CPOS is reset to zero when the reference crank angle signal REF is generated, and thereafter, is counted up to a value obtained by counting up the number of generated position signals POS.

The routine shown in the flowchart of Fig. 8 is interruptedly executed at each time when the cam angle signal CAM is output from cam sensor 132.

In step S31, a value of counter CPOS at the time is read.

The value of counter CPOS indicates a rotation angle of from the time when the reference crank angle signal REF is generated to the time when the cam angle signal CAM is generated.

In step S32, a detection value θ_{det} of the angle value (rotation phase) of camshaft 134 relative to crankshaft 120 is calculated based on the value of counter CPOS.

Accordingly, the detection value θ_{det} is updated at each time when the cam angle signal CAM is generated.

On the other hand, the flowchart of Fig. 9 shows the routine of feedback control of variable valve timing mechanism 113, and this routine is interruptedly executed at each predetermined short time of period (for example, 10msec).

In step S41, the detection value θ_{det} is read.

In step S42, it is judged whether or not a detection value $\theta_{det.1}$ read at the previous execution of this routine is equal to the detection value θ_{det} read at present time.

To be in detail, in step S42, it is judged whether or not $|\theta_{det} - \theta_{det.1}| \leq \alpha$.

When the previous value $\theta_{det.1}$ differs from the present value θ_{det} , it is judged that it is the timing immediately after the detection value θ_{det} is updated, and the control proceeds to step S43.

In step S43, the detection value θ_{det} read at the present time is set to an actual angle θ_{now} to be used for the feedback control.

Contrary to the above, when the previous value $\theta_{det.1}$ is equal to the present

value θ_{det} , it is judged that it is the second or subsequent timing after the detection value θ_{det} is updated, and the control proceeds to step S44.

In step S44, the currents (or voltages) of electromagnetic brakes 26 and 27 are detected.

In the case where the current (voltage) is controlled by duty controlling the power supply to each of electromagnetic brakes 26 and 27, it is possible to set a duty control signal to a value equivalent to the current (voltage).

Further, the current or voltage may be measured by means of an ammeter or a voltmeter.

In the above current (voltage) detection, the current (voltage) of first electromagnetic brake 26 is indicated by plus sign and the current (voltage) of second electromagnetic brake 27 is indicated by minus sign, so that the current (voltage) in the advance direction and the current (voltage) in the retarded direction can be distinguished from each other.

Then, in step S45, a current value I is converted into a conversion value θ_{pr} based on a transfer function $G(s)$ indicating a correlation of the current and the phase advance value.

In step S46, a difference $\Delta\theta_{pr}$ between a conversion value θ_{pr-1} obtained in step S45 at the previous execution and the conversion value θ_{pr} obtained in step S45 at the present execution, is calculated.

$$\Delta\theta_{pr} = \theta_{pr} - \theta_{pr-1}$$

In step S47, a result obtained by adding $\Delta\theta_{pr}$ to an actual angle θ_{now-1} set at the previous execution, is set as the actual angle θ_{now} of the present time.

$$\theta_{now} = \theta_{now-1} + \Delta\theta_{pr}$$

Accordingly, in the case where the present routine is executed two times or more at generation intervals of cam angle signal CAM in the low rotation state of the engine, in the second or subsequent execution of the routine, a subsequent change in the advance value is estimated based on the currents (voltages) of electromagnetic brakes 26 and 27, with the recent detection value θ_{det} being a reference (see Fig. 11).

Then, in step S48, the target advance value (target rotation phase) is determined based on the engine operating conditions (engine load, engine rotation speed).

In step S49, the power supply to electromagnetic brakes 26 and 27 is feedback controlled based on a deviation between the actual angle θ_{now} and the target advance value.

Note, in the steps shown in the flowchart of Fig.9, steps S41 to S47, that is, the process of obtaining the actual angle θ_{now} , can be shown in a block diagram of Fig. 10.

In the case where the detection value θ_{det} is used as it is to feedback control the power supply to electromagnetic brakes 26 and 27, and also the engine is in the low rotation state, the power supply to electromagnetic brakes 26 and 27 is feedback controlled based on a value different from the actual advance value, during the detection value θ_{det} is updated.

However, if the change in the rotation phase during the detection value θ_{det} is updated is estimated to update the actual angle θ_{now} as in the above constitution, it is possible to feedback control the power supply to electromagnetic brakes 26 and 27 based on an angle closer to the actual advance value, even in the engine low rotation state. Thus, the overshooting of rotation phase can be avoided.

Moreover, the conversion value θ_{pr} obtained by converting the currents (voltages) of electromagnetic brakes 26 and 27 based on the transfer function, is not set to the actual angle θ_{now} for control just as it is, but a change portion of the conversion value θ_{pr} is sequentially integrated on the detection value θ_{det} obtained based on the sensor signal. Therefore, even if there is an error in the conversion value θ_{pr} , it is possible to set accurately the actual angle θ_{now} for use in the control.

The variable valve timing mechanism may be of another constitution in which a rotation phase of a camshaft relative to a crankshaft is varied by an actuator. Further, the actuator is not limited to the electromagnetic brake.

The entire contents of Japanese Patent Application No. 2002-318371 filed on October 31, 2002, a priority of which is claimed, are incorporated herein by reference.

While only a selected embodiment has been chosen to illustrate the present invention, it will be apparent to those skilled in the art from this disclosure that various

changes and modifications can be made herein without departing from the scope of the invention as defined in the appended claims.

Furthermore, the foregoing description of the embodiment according to the present invention is provided for illustration only, and not for the purpose of limiting the invention as defined in the appended claims and their equivalents.